Stable carbon isotopes as powerful tools for studying land-atmosphere flux exchanges and improving land surface models

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The stable isotopic compositions of carbon and oxygen in terrestrial plants can provide valuable insights into plant eco-physiological responses to environmental changes at seasonal to annual resolution. Yet, the potential of these datasets to study land-atmosphere interactions remains under-exploited. Here, we present some examples of how stable carbon isotopes (δ13C) measured in plant materials (leaves and tree-rings) can be used to explore changes in the magnitude and variability of carbon and water flux exchanges between the vegetation and the atmosphere and to improve land surface models.

First, we show that the discrimination against 13C (Δ13C), calculated as the difference in δ13C between the source atmospheric CO2 and the plant material studied, varies strongly between regions and biomes and is useful for better understanding the CO2 fertilisation effect of plant growth. For example, tree-ring Δ13C records from boreal evergreen forests in North America increased linearly with rising CO2 during the 20th century, suggesting that those forests have actively contributed to the land carbon sink by removing CO2 from the atmosphere at a relatively constant rate. However, such an increase in Δ13C with rising CO2 is not observed everywhere. We found that over the same time period, while some forests had a fairly constant Δ13C, others exhibited a slight decrease in Δ13C over time, which might indicate a reduction of the capacity of trees to absorb CO2. Using a response function approach, we show that the differences between sites and regions are most likely the result of different evaporative demands and soil water availability conditions experienced by forests.

We then discuss how predictions of the coupled carbon and water cycles by vegetation models can be improved by incorporating stable carbon isotopes to constrain the model representation of carbon-water fluxes regulation by leaf stomata. Specifically, we examine and evaluate simulations from the JULES vegetation model at different eddy-covariance forest sites where stable carbon isotopic data and canopy flux measurements are available. Overall, our analyses have strong implications for the understanding of historical changes in the strength of the CO2 fertilisation effect and in the water use efficiency of terrestrial ecosystems across regions.